Zenithal Bistable Device (ZBD) using Plastic Substrates

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Abstract

High contrast reflective ZBD cells have been made using PES polymer substrates. A written image is maintained after compression or flexing of the cell which is unique for bistable LCDs. Cells have also been made containing PEDOT polymer electrode layers.

Introduction

The use of plastic instead of glass substrates in display manufacture is seen as a key step in reducing weight and thickness while also reducing screen breakage which plagues many portable display products. Furthermore plastic substrates allow conformal displays which can be mounted on curved surfaces as well as roll up displays which would provide ultimate portability.

The currently exploited LCD technologies are supertwisted nematic and active matrix twisted nematic but both these show difficulties in migrating to plastic. Supertwist requires very tight control of cell gap and pretilt in order to achieve high multiplexing and good contrast. These aspects are harder to control on a plastic substrate. Active matrix displays require multi step high resolution photolithography and so are harder to make on plastic due to dimensional changes (induced by liquid absorption or temperature variation) as well as the low maximum working temperature.

An alternative approach to plastic LCDs is to use a bistable display mode which has a well defined threshold and so can be infinitely multiplexed without an active matrix. Bistable FLC displays have been demonstrated using plastic substrates [1] but these will suffer alignment damage if subjected to point pressure. Bistable nematic technologies such as BTN [2] or BCh [3] do not suffer alignment damage but are vulnerable to flow induced switching since they rely on bulk bistability, i.e. a written image would be erased by flexing the display.

The ZBD (zenithal bistable display) [4-8] is an example of a bistable nematic LCD which is unique in relying on surface rather than bulk bistability and makes it the only bistable LC technology which can retain a written image after the application of shock. ZBD relies on an optimised micron scale grating surface which can stabilise two LC configurations with two different tilt angles. Both states are insensitive to mechanical shock but can be electrically switched by pulses of defined polarity which couple to flexoelectric and ordoelectric polarisations present in the vicinity of the grating surface. This switchable surface can be placed opposite any other alignment surface leading to a wide choice of bulk alignment states which can be optimised for high contrast, good viewing etc. The required switching voltage for ZBD has been found to vary linearly with cell gap [4]. However a ZBD cell with a cell gap variation can be fully switched by simply applying sufficient voltage to switch the thickest regions. Thus ZBD is a strong candidate for highly multiplexed plastic LCDs which are cell gap tolerant.

This paper describes the fabrication and properties of ZBD cells made using PES substrates. PES was chosen since it combines low optical retardation (<10nm) with a high maximum working temperature (200°C). In addition, the PES substrate includes an SiO_2 layer which prevents the oxygen or moisture from entering the cell. Results are also described using plastic substrates carrying PEDOT electrodes. The PEDOT layers have higher resistivity than ITO and lower transmission but they have higher ruggedness and can be flexed and folded without loss of conductivity.

Fabrication method

Cells were fabricated using either 100μm PES substrates with ITO electrodes or 175μm PET substrates with PEDOT electrodes. In the latter case the significant polymer birefringence was oriented so that it was parallel to adjacent polariser directions and so did not affect cell optics at normal incidence.

ISSN1083-1312/00/2001-029-$1.00 + .00 © 2000 SID

Electrode patterning was carried out using 10% sulphuric acid for ITO and sodium hypochlorite (10-13% chlorine) for PEDOT. In the latter case the patterning is by virtue of polymer deactivation rather than removal. All subsequent processes were common to both types of substrate.

The sample was coated in a 0.9μm layer of photoresist (Shipley 1813) by spin coating. A 1μm pitch grating was then exposed into this layer by using off-axis hard contact photolithography with a chrome on glass mask. After development, the photoresist grating was hardened with exposure to deep UV and baking to 160°C. Finally the grating was post-processed in order to induce the required homeotropic alignment in the LC.

The opposite flat substrate in the ZBD cell carried an array of photo defined cell spacers of the required height (3.6μm). These were patterned in an epoxy based resist (MicroChem SU8-25) using a mask consisting of 50μm circles on a 250μm pitch. Monostable planar alignment on this substrate was achieved using the photoalignment material LPP F310 CP (Ciba). This was spin coated, baked at 130°C and then exposed to UV radiation at an angle of 20° to the normal (0.6 J/cm^2 at 325nm). These conditions induced a pretilt of about 1.0°.

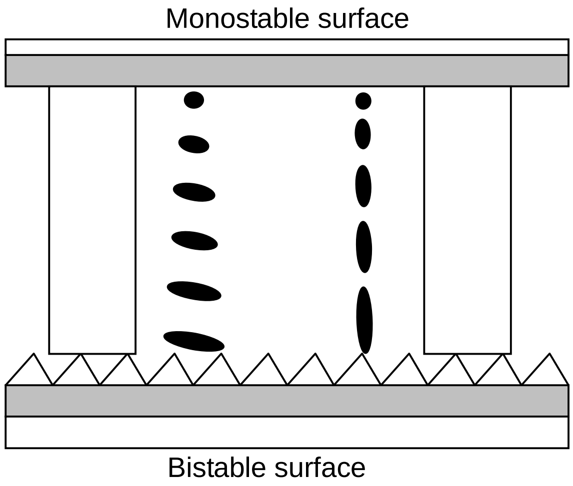

Figure 1. Schematic of plastic cell design.

Once the substrates have been processed, the cell was constructed, filled and sealed under reduced pressure so that the cell gap remains well defined by the photo spacers. A commercially available STN material was used in the cell. Figure 1 shows a schematic of the cell geometry. This arrangement of surfaces leads to a bulk LC configuration which is either hybrid or twisted. The cell also contains a few degrees of pre-twist between the top and bottom surface to remove reverse twist states. A reflective polariser (RDF-C, 3M) and a front polariser (Nitto AR) were added so that the twisted state is black in reflection and the hybrid state is white. This arrangement has been found to lead to wide viewing angle and high contrast (>40:1) [5]. The cell gap was designed so that the twisted state achieves first minimum conditions.

Results

1. Electrode ruggedness

The effect of substrate bending on electrode resistivity was tested on unprocessed substrates. Table 1 shows the effect of bending and folding on the resistance on square samples. The results show that ITO layers start to break up for a small bend radius. In contrast, the PEDOT layer remains conductive even after the substrate has been folded. In fact repeated folding of this substrate failed to break the PEDOT layer.

Physical deformation of sample	Resistance of ITO on PES	Resistance of PEDOT on PET
No deformation	151Ω	323Ω
Bend (r=4.5mm)	153Ω	328Ω
Bend (r=1.5mm)	1363Ω	332Ω
Fold (r≈0.1mm)	0.6MΩ	345Ω

Table 1. Resistance measured after relaxation from various substrate deformations. (Electrode layer on outside of bend).

2. Cell spacer walls

Figure 2 shows a region of the cell between crossed polarisers. Examination of the LC retardation beneath each spacer pillar suggested that close contact between the pillar and the opposite substrate was consistently achieved. Observation of the cell during switching showed that the pillars did not affect the stability of either state and do not significantly modify the switching in the region around the pillars. This is in contrast to other bistable LCDs where spacer pillars have been known to seed defects and compromise long term bistability.

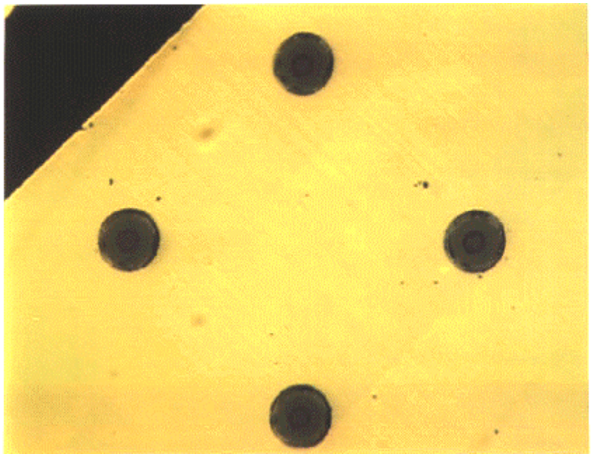

Figure 2. Region of cell showing spacer walls

3. Cell optics

Prior to addition of polarisers, cells were examined in transmission under a polarising microscope. The ITO on PES samples transmitted 72% of the incident polarised light in the twisted state (photopic response) and had a contrast ratio of 59:1. The PEDOT on PET sample transmitted 48% of the incident polarised light and had a contrast ratio of 27:1. Therefore the absorption of the PEDOT layer did compromise cell throughput. This sample also had poor contrast at angles greater than 20-30° but this was due PET birefringence and can be easily removed by using an isotropic substrate. The lower contrast for the PET sample was due to slight misalignment between the PET optic axes which again can be improved by using an isotropic polymer.

4. Cell Switching

The switching response of a typical plastic ZBD cell is shown in figure 3. The first curve represents the voltage at which any switching occurs within the 1cm^2 active area while the second curve records the voltage for full switching across the active area. The size of the partial switch width between these curves dictates the split in voltage between rows and columns in a matrix addressed device. The data in figure 3 implies that such a device could be addressed with a data (column) voltage of only ±1.30 V at a pulse width of 1ms. Therefore the use of plastic substrates has not compromised the multiplexibility of ZBD. Indeed the performance shown in figure 3 is consistent with infinite multiplexibility although in practice the complexity of a matrix would always be limited by minimum electrode widths, ITO conductivity and driver costs. The cell gap uniformity in current cells has not been measured but it is likely that further improvements in switching uniformity could be achieved since these cells were not fabricated under cleanroom conditions.

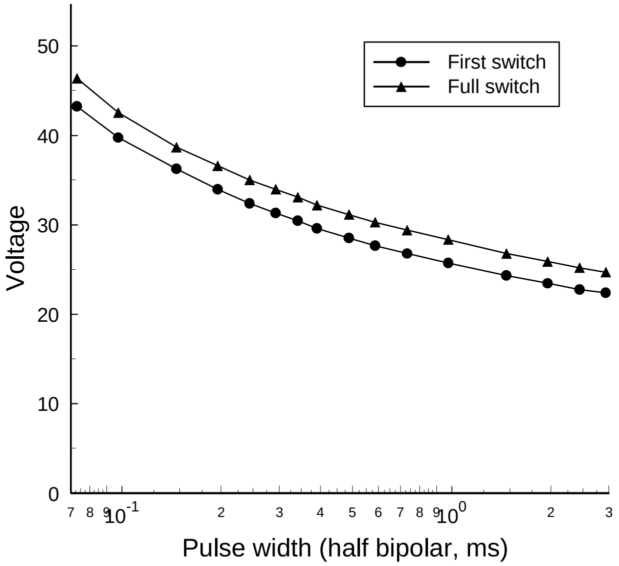

Figure 3. Typical switching curve form a plastic ZBD cell

Figure 4 shows a photo of a typical test cell. The overall thickness is 800µm although much of this is the thickness of the polarisers. Flexing of the cell does not disturb the switched state except for brief optical transients which are due to flow in the bulk of the LC. Furthermore the cell is not affected by moderate point pressure.

Conclusions

This paper has shown that the ZBD configuration can be made using plastic substrates. To our knowledge this is the first example of a plastic bistable LCD which can retain a written image after mechanical shock (flexing or point pressure). Furthermore the cell structure is one which could ultimately be made in a roll to roll process using embossing as a means for creating the surface features required on each substrate.

Matrix addressed plastic cells are currently under construction and will allow further confirmation of the cell-gap-tolerant multiplexing of ZBD. The adhesion and integrity of the ITO layer was found to be sufficient to allow fairly severe flexing of a display but it is possible that PEDOT would be more suitable for folding or roll up displays if they should become required.

Plastic displays have clear advantages for portable products in terms of weight, thickness as well as ruggedness and could eventually be made by lower cost manufacturing processes. The use of plastic substrates in combination with ZBD can further reduce product weight by virtue of the lower power consumption of this bistable mode.

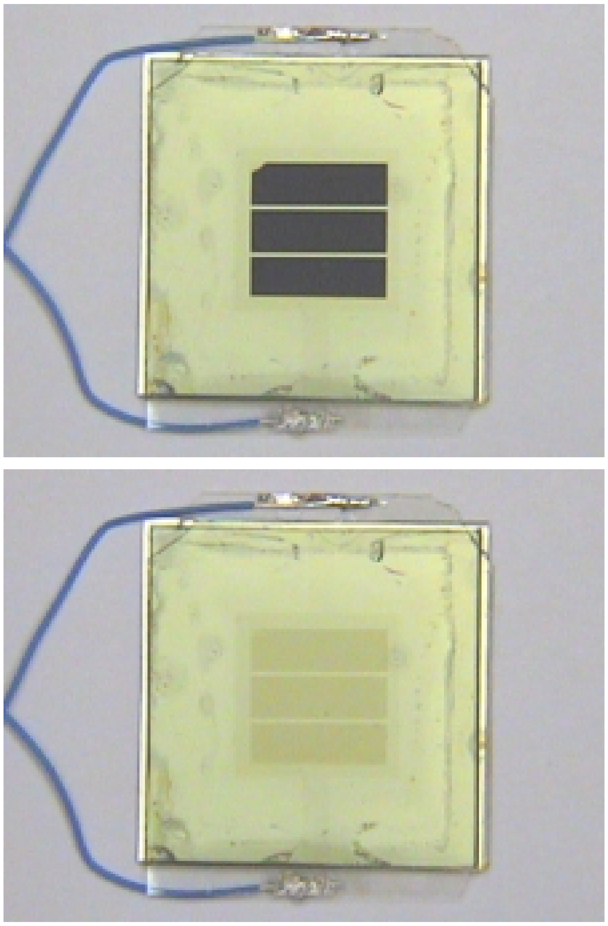

Figure 4. Photos of plastic ZBD test cell

Acknowledgements

The author acknowledges Dr N. D. Young (Philips, UK) for the supply of PES films, Mr. T. Cloots (Agfa, Belgium) for the supply of PEDOT on PET and Mr S Barny (Ciba) for the supply of photoalignment material.

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